

BIOSOILDS APPLICATION ENHANCES CARBON SEQUESTRATION IN SOILS

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Abstract

Applying organic amendments including biosolids and composts to agricultural land could increase C storage in soils and contribute significantly to the reduction of greenhouse gas emissions. Although a number of studies have examined the potential value of biosolids as a nutrient source, there has been only limited work on the potential impact of biosolids application on C sequestration in soils.

The objective of this study was to examine the potential value of biosolids in C sequestration in soils. Two types of experiments were conducted to examine the effect of biosolids application on C sequestration. In the first laboratory incubation experiment, the rate of decomposition of various organic amendments including biochar, biosolids and green waste composts was examined using a number of soils collected from different land-use practices. In the second field experiment, the effect of biosolids on the growth of *Arundo donax* (giant reed), *Brassica juncea* (Indian mustard) and *Helianthus annuus* (sunflower) on a landfill site was examined in relation to biomass production and C sequestration. The rate of decomposition varied amongst the organic amendments and also soil types. Biosolids application increased the biomass of all three plant species, thereby increasing the C input to soils. The rate of net C sequestration resulting from biosolids application was higher for giant reed than mustard and sunflower. Biosolids application is likely to result in a higher level of C sequestration when compared to other management strategies including fertilizer application and conservation tillage, which is attributed to increased microbial biomass, and Fe and Al oxides-induced immobilization of C.

Introduction

Global warming is a critical environmental issue of the 21st century and the carbon (C) cycle plays a major role both in the cause and remediation of the global climate change (Scholes and Noble 2001). Recent concerns over increased atmospheric carbon-dioxide (CO₂) have increased interest in the investigation of soil organic C (SOC) changes and C sequestration capacity in various ecosystems (Bandaranayake *et al.*, 2003). Promoting soil C sequestration is considered as an effective strategy for reducing atmospheric CO₂ (Lal *et al.*, 2003). Indeed, soil C sequestration is an important option not only to mitigate climate change but also to enhance soil fertility and the productivity of agroecosystems (Dawe *et al.*, 2003; Janzen, 2006; Manlay *et al.*, 2007).

Carbon sequestration in soil has been recognised as one of the possible measures through which greenhouse gas emissions can be mitigated (IPPC, 2006). Carbon sequestration occurs when a positive disequilibrium between C inputs and outputs is sustained over some period of

time, with the system eventually achieving a new, higher steady-state in C inputs in soils (Jastrow *et al.*, 2007). In addition to increasing plant C inputs, strategies for enhancing soil C sequestration include reducing C turnover and increasing its residence time in soils. Two major mechanisms, (bio) chemical alteration and physicochemical protection, stabilise SOC and thereby control its turnover. Key practices to increasing the C sequestration potential of soil include increasing the period under which the soil is vegetated, and minimising cultivation and other soil disturbances (Cole *et al.*, 1997; Jastrow *et al.*, 2007). Strategies for increasing C sequestration in soils include conservation tillage, application of organic waste such as biosolids and composts, and improved crop rotation involving cover crops (Lal *et al.*, 2003). However, capitalising on this potential climate-change mitigation measure is complicated by the fact that intensive farming practices generally lead to the depletion of C from soil, thus reducing its capacity to act as a C sink.

Applying organic wastes including biosolids and composts to agricultural land could increase C storage in soils and contribute significantly to the reduction of greenhouse gas emissions. Thus these organic wastes can contribute to both restoring soil quality and sequestering C in soils. Applications of organic wastes can lead either to a build-up of soil C over time, or a reduction in the rate at which C is depleted from soils. Therefore the application of organic wastes to cultivated soils is likely to reverse the decline in soil C storage, thereby contributing to the build-up in the stable C fraction in soils.

Large quantities of biosolids, ranging from approximately 0.07×10^6 Mg yr⁻¹ in Australia to 7.5×10^6 Mg yr⁻¹ in the USA are generated (Park *et al.*, 2011). With the increased economic restraints and environmental concerns about land-filling and incineration, interest in land application of biosolids could continue to grow. Biosolids have the potential for being recycled on agricultural and degraded lands, and land application of biosolids is considered as an integrated approach to managing increasing production of this waste resource. Beneficial use through land application is based on their ability to favourably alter soil properties, such as plant nutrient availability, soil reaction, organic matter content, cation exchange capacity (CEC), water holding capacity, and soil tilth (Haynes *et al.*, 2009). Recently there has been increasing interest in the use of organic amendments including compost and biosolids for enhancing C sequestration. Unfortunately, a substantial proportion of biosolids are not re-used for beneficial purposes (i.e. land application, contaminated site reclamation, energy production) due to local public opposition and potential hazards, and are disposed of in landfills.

Optimum use of these byproducts requires knowledge of their composition not only in relation to beneficial uses but also to environmental implications. Environmental concerns associated with the land application of biosolids encompass all aspects of non-point source pollution that include increased metals input, contamination of surface water with soluble and particulate P, leaching losses of N in subsurface drainage and to groundwater, and reduced air quality by emission of volatile organic compounds. Although a number of studies have examined the potential value of biosolids as a nutrient source, there has been only limited work on the potential impact of biosolids application on C sequestration in soils (Haynes *et al.*, 2009). Thus, maintaining the quality of the environment is a major consideration when developing management practices to effectively use biosolids as a nutrient and C resource and soil conditioner in agricultural production system.

The objective of this study was to examine the potential value of biosolids in C sequestration in soils. Two types of experiments were conducted to examine the effect of biosolids

application on C sequestration. In the first laboratory incubation experiment, the rate of decomposition of a biosolids sample was examined using a number of soils collected from different land-use practices (vineyard, vegetable cultivation, arable cropping and sports turf). In the second field experiment, the effect of biosolids on the growth of *Arundo donax* L. (giant reed), *Brassica juncea* (L.) Czern. (Indian mustard) and *Helianthus annuus* L. (sunflower) on a landfill site was examined in relation to biomass production and C sequestration.

Methods and Materials

Soil and organic amendment samples

For the laboratory incubation experiment a number of surface (0-15 cm depth) soil samples from different land-use practices (vineyard, vegetable cultivation, arable cropping, permanent pasture, sports turf, shooting range and mining) were used in this study. The field experiment was conducted in a landfill site. The organic amendments used in this study include poultry manure compost, poultry manure biochar and biosolids.

Laboratory incubation experiment

The objective of the laboratory incubation experiment was to examine the rate of decomposition of the three organic amendment sources in a range of soils derived from various land-use practices. The decomposition of organic amendments was measured by monitoring the release of CO₂ using respiration flasks. The soil samples were mixed with organic amendments at a rate of 50 g C/kg soil, corresponding to approximately 25 Mg organic matter per ha to a depth of 5 cm. The soil samples were placed in 3-dm³ jars containing a CO₂ trap (30 mL of 1 M NaOH), and a beaker containing water to maintain a water-saturated atmosphere. Additional jars containing only the CO₂ traps and water served as blanks. The jars were then incubated in the dark at 24°C. Three jars per treatment were removed at various intervals for the analysis of CO₂ in the NaOH trap and total C in soil samples.

The first-order decay rate equation was used to calculate the decomposition rate of C:

$$N = N_0 \exp (-kt) \quad (1)$$

where N_0 is the initial amount of C recovered at day 0 (g C/kg soil), N is the concentration of residual C in the soil at that instant in time (g C/kg soil), t is incubation period (days) and k is the first-order decay rate constant (per time). The C half-life ($t_{1/2}$ = time (day) taken to reduce C concentration to half of the initial value) was calculated from the rate constant.

Field experiment

The field experiment was conducted at a landfill site (~17 ha) located at Coleman road in South Australia, Australia. The municipal landfill began operation in 1950's and received general municipal waste, including green waste, up to 1997. Subsequently, the landfill was capped with local soil material consisting of high clay from subsoil environments. The main objective of the field experiment was to examine the value of biosolids in phytocapping landfill sites using a number of plant species.

The experimental plot used was divided up into 3 separate areas for different levels of biosolids application. Biosolids were added to respective plots in November 2008. The experimental layout consists of three levels of biosolid application as main treatments and 3 plant species as subplots. Each main plot (200 m²) was amended with biosolids from Bolivar Treatment Plant at rates of either 0, 25 or 50 Mg ha⁻¹. Biosolids were mixed approximately to

the top 0.2 m of the soil and tilled manually. Each experimental plot was planted with Indian mustard, sunflower and giant reed. Plants were watered once to twice per week using drip irrigation. While Sunflower and Indian mustard were resown after each harvest, the giant reed was allowed to regrow as a ratoon crop.

Plant and Soil Analysis

Soil samples were taken at two depths (0-20cm and 20-40cm) at various periods, before the commencement of the experiment, immediately after biosolids application, and then at 12 months interval. Experimental plots had 5 auger cores sampled using a stainless steel auger. Portions of each soil were separated and air-dried. Fresh soils were stored at 4°C until used. Dried soil samples were ground and passed through 2 mm sieves. The soil samples were analysed for various properties including pH, total C and plant nutrients.

Plants were harvested annually by sampling in five 1 m² areas. Plant materials were dried at 70°C for 72 h before grinding. Root biomass was also measured for selected treatments and total biomass production from each plot was estimated based on the relationship between shoot:root ratio and shoot weight from the measured areas.

Results and discussion

Decomposition of organic amendments

The laboratory incubation experiment indicated that the rate of decomposition as measured by half life ($t_{1/2}$) varied between the organic amendments. There was a negligible decomposition of biochars and the rate of decomposition of composts and biosolids was much higher than biochars, with $t_{1/2}$ values ranging from 160 days (poultry manure compost) to 10235 days (poultry manure biochar). The rate of decomposition of biosolids was slightly less than that of poultry manure. It has often been noticed that the rate of decomposition is much higher for composts and biosolids than biochars (Wardle *et al.*, 2008; Steinbeiss *et al.*, 2009) which has been attributed to the difference in the nature of C in the organic amendments. Both physical and chemical fractionation studies involving soil C have demonstrated that labile C fractions decompose faster than non-labile C fractions (Bernal *et al.*, 1998). The physical and chemical structure including surface area, condensation grade and particle size of biochars control their stability in soils (Wardle *et al.*, 2008; Ro *et al.*, 2010).

The rate of decomposition of biosolids varied amongst the soil types. It was slightly less in vineyard soil, copper mine soil and shooting range soils than soils from other land use practices. The former three soils are enriched with metals such as Cu and Pb. For example, the vineyard soil contains slightly higher level of Cu than other soils resulting from regular application of Cu fungicides, which may be one of the reasons for the decrease in the decomposition of composts. Similarly, the shooting range soil was rich in lead and antimony. Metal contamination inhibits microbial activity, thereby affecting the decomposition of organic matter (Giller *et al.*, 1998; Verma *et al.*, 2010). It also been shown that a number of metals including Cu and Pb form both soluble and insoluble complexes with organic matter, thereby inhibiting the supply of free C for decomposition (Bolan *et al.*, 2011).

The soils varied in texture and there was a negative relationship between clay content and rate of decomposition. Depending on the microbial activity of soils, organic amendments tend to decompose slower in clay soils than sandy soils which has been attributed to greater immobilisation or occlusion of C and lower aeration in the former soils. Sissoko and Kpomblekou (2010) noticed that the $t_{1/2}$ values for broiler litter ranged from 18 to 693 days

for a range of soils which they attributed to the difference in texture and microbial activity between the soils. With the same input of organic material, clay soils usually accumulate more organic matter than sandy soils (Schmidt and Kögel-Knabner, 2002; Laganière *et al.*, 2010). The stabilising effect of organic matter in soils has been ascribed to adsorption of organics onto surfaces such as clays, encapsulation between clay particles or entrapment in small pores in aggregates inaccessible to microbes (Oades, 1989). In sandy soils, microorganisms have more access to organic matter than in heavy textured soils where microbial access is limited because of sorption of organic C onto soil minerals (Sissoko and Kpombrekou, 2010).

Field experiment

Soil properties

Amendment of landfill site with biosolids significantly improved the physical, chemical and biological characteristics of the soil. For example, with increasing level of biosolids application, while the bulk density and pH decreased, the CEC, organic matter and microbial activity increased. Application of organic amendments such as composts, manures and biosolids has often been shown to decrease soil bulk density which is attributed to the increase in porespace. The effect of organic amendments on soil pH depends on the pH of the original soil, pH buffering capacity of both soil and organic amendments and the proton dissociation constants (k_d) of various functional groups in organic amendments. The increase in CEC with biosolids application could be attributed to the contribution of surface charge by the biosolids and the biosolids-induced change in soil pH. Functional groups of compounds in biosolids can act as sinks for H^+ and OH^- , and thus increases pH buffering capacity. The increase in microbial activity as measured by basal respiration with increasing biosolids application could be attributed to the increased supply of nutrients and C (Haynes *et al.*, 2009).

Plant growth

The dry matter yields of both shoot and root of each plant species increased in response to biosolids addition, but in general, the beneficial effect of biosolids application on plant dry matter yield decreased with time after its application. The root:shoot ratio of plant species ranged from 0.15 in the case of Arundo to 0.25 in the case of mustard and there was no effect of biosolids application on this ratio. This indicates that the increase in plant dry matter yield with biosolids application may be attributed to the improvements in soil physical, chemical and biological fertility, thereby contributing to the overall performance of all plant species. For example, biosolids application provided around 100, 53 and 125 kg N, P and K per hectare at the highest rate of application. The increase in root biomass is with biosolids application is likely to contribute to the increased C storage in soil.

Carbon storage

The effect of biosolids application on soil C storage was monitored by measuring soil C at regular intervals. The soil organic C content increased with biosolids application. Biosolids application increases soil C storage through direct supply of organic matter to soil and also indirectly by increasing root biomass. Soil organic matter increases have often been shown to relate strongly to improvements in plant productivity on marginal lands. The C storage in the soil was estimated from C inputs from biosolids application and root biomass production.

$$\text{Carbon storage} = [\text{Biosolid residual C} + \text{Root Biomass (with biosolid} - \text{control)}] \quad (2)$$

$$\text{Biosolid residual carbon} = \text{Soil C (with biosolid} - \text{control)} \quad (3)$$

Soil C increased from 0.07% (control) to 0.62% (50Mg BS/ha), resulting in a total biosolid residual C of 6.55 Mg/ha for this treatment. There was no difference in biosolid-derived residual C amongst the plant species (Table 1). However, the root biomass C was slightly higher for Arundo than the other two species (Figure 1). The data in Table 1 indicate that the rate of increase in C (Mg C/ha/yr/Mg biosolids) was higher for Arundo (0.807) than Mustard and Sunflower (0.567). In a long-term field trial examining the value of biosolids application for land reclamation, Tian *et al.* (2009) noticed that C sequestration was positively correlated to biosolids loading rate with a mean rate of 0.064 Mg C/ha/yr/Mg biosolids. Similarly, Soriano-Disla *et al.* (2010) indicated that application of biosolids at a rate of 50Mg/ha in 60 agricultural soils resulted in an increase of about 1.7 g C/kg soil (1.7Mg C/ha).

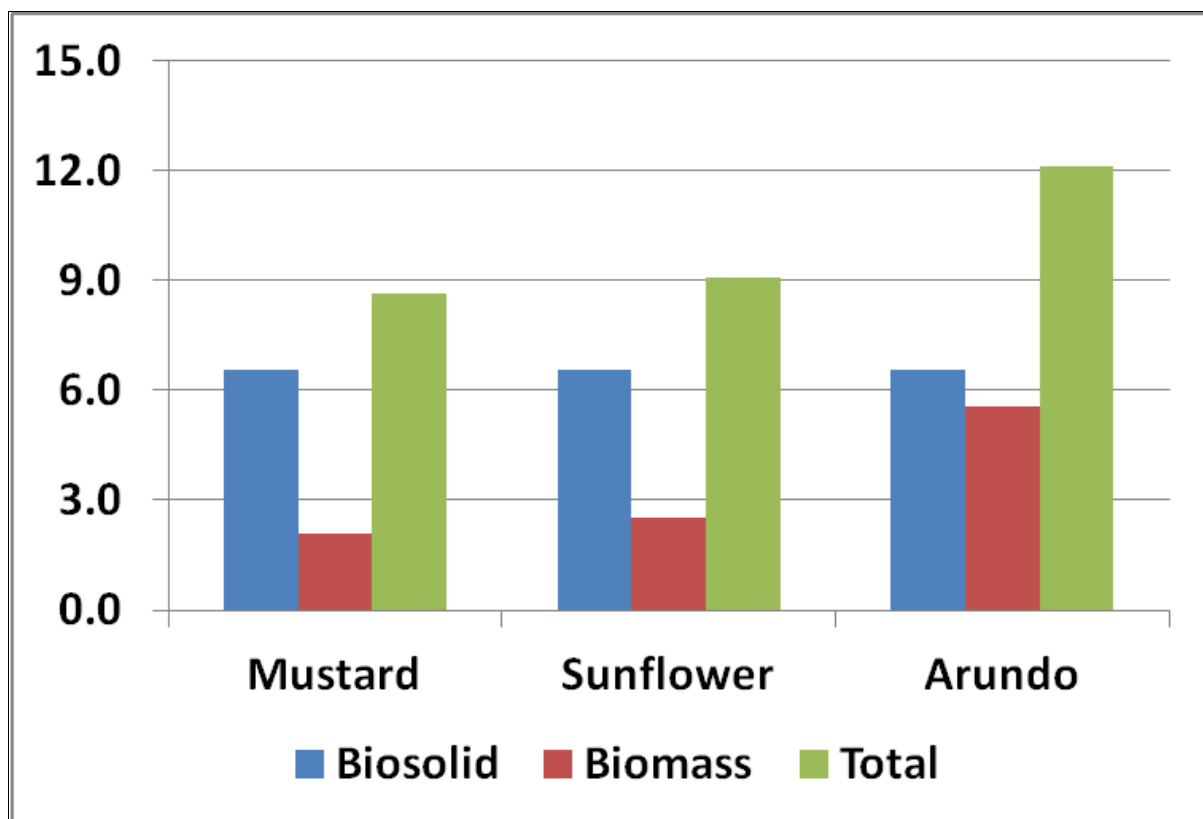


Figure 1. Effect of biosolid application (50 Mg BS/ha) on carbon storage (MgC/ha) resulting from residual biomass carbon and root biomass.

Table 1. Carbon storage by biosolid @ 50Mg BS/ha

Plant species	Biosolid residual C (Mg C/ha)	Root biomass C (Mg C/ha)	Total C (Mg/ha)	Rate of C storage (MgC/Mg BSC)
Mustard	6.55	2.10	8.65	0.576
Sunflower	6.55	2.52	9.07	0.604
Arundo	6.55	5.56	12.11	0.807

Farm yard manure is the most commonly used organic amendments aimed at improving soil fertility including build up in soil organic C. However, it has often been noticed that biosolids application resulted in a higher build up in soil organic C than manure composts which has been attributed to the greater recalcitrant C in the former (Gerzabek *et al.*, 2001).

It has often been observed that application of organic amendments results in a higher level of C sequestration when compared to other management strategies including fertilizer application and conservation tillage. For example, Paustian *et al.* (2002) and West and Post (2002) observed net C sequestration rates of 0.25 and 0.57 Mg/ha/yr, respectively resulting from conservation tillage practices. Tian *et al.* (2009) attributed a number of reasons for the high C sequestration resulting from biosolids application that include increased microbial biomass, and Fe and Al oxides-induced immobilization of C.

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